Influence of solar UVA on erythemal irradiances

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Short Title: Influence of solar UVA on erythemal irradiances

Citation: *Parisi, Alfio and Turnbull, David J. and Kimlin, Michael G. (2006)* Influence of solar UVA on erythemal irradiances. *Physics in Medicine and Biology, 51. pp. 3241-3249.*

Abstract

Many materials in everyday use such as window glass in homes and offices, glass in sunrooms and greenhouses, vehicle glass and some brands of sunscreens act as a barrier to the shorter UVB wavelengths while transmitting some of the longer UVA wavelengths. This paper reports on the erythemal exposures due to the UVA waveband encountered over a 12-month period for an SZA range of 4^o to 80^o and the resulting times required for an erythemal exposure of one standard erythemal dose (SED) due to the erythemal exposures to the UVA wavelengths. The minimum time for an exposure of one SED due to the UVA wavelengths in winter is approximately double that what it is in summer. The time period of 40 to 60 minutes was the most frequent length of time for an exposure of one SED with 60 to 80 minutes the next frequent length of time required for a one SED exposure.

1. Introduction

Transmission of UV radiation through glass will remove the UVB (280-320 nm) component and transmit a component of the UVA (320-400 nm) wavelengths. The International Commission on Illumination (CIE) has defined the UVB-UVA boundary at 315 nm. The boundary at 320 nm has been widely used in the literature (Christiaens *et al* 2005) and will also be employed in this research. The UVA component that is transmitted is influenced by the thickness of the glass, angle of incidence on the glass and the type and amount of window tinting (Bartels and Loxsom 1995; Parisi *et al* 2004). Additionally, laminated glass transmits less than non-laminated glass (Hampton *et al* 2004; Kimlin and Parisi 1998). The spectral transmission of the windshield in cars occurs for wavelengths above 380 nm (Sliney *et al* 1995). Examples of environments where population groups are exposed to this filtered UV are in offices and homes behind window glass, in glass greenhouses (Parisi and Wong 1997a), sunrooms (Parisi and Wong 1997b) and in vehicles with untinted windows wound up. The UVA in cars has been described with the use of dosimeters (Parisi and Wong 1998; Moehrle *et al* 2003), radiometers (Parisi and Kimlin 2000) and spectroradiometers (Kimlin *et al* 2001).

Another environment where the UV is filtered is where a sunscreen has been applied and the solar UV is filtered through to the skin. Sunscreen products provide different amounts of absorption in the UVA waveband and products with the same SPF may have differing UVA absorption (Baron *et al* 2003). Sunscreen products that have a high SPF rating may still transmit a significant proportion of the UVA wavelengths. For example, only 10% of 59 sunscreen products tested achieved a critical absorption wavelength of 370 nm or greater (Diffey *et al* 2000).

For the environments where the UVB wavelengths have been filtered out, the UVA wavelengths may still contribute to erythemally effective exposures (Parisi and Kimlin 2005). This is particularly the case if the exposures are cumulative or over an extended period. Additionally, the solar UV irradiances in the UVA waveband are higher than the irradiances in the UVB waveband. Previous research shows that repetitive exposures to sub-erythemal UVA can have a cumulative influence to result in skin alterations indicative of early tissue damage (Lavker *et al* 1995) and premature skin photoaging and wrinkling (Bissett *et al* 1992) as well as implicated in immunosuppression (Fourtanier *et al* 2006). An action spectrum for the induction of melanoma in humans does not exist, however an action spectrum has been derived for the induction of melanoma in a hybrid fish (Setlow *et al* 1993). This fish action spectrum shows that the UVA waveband up to 365 nm is significantly influential in the induction of melanoma in this species and it may be indicative that the UVA wavelengths have a role in the induction of melanoma in humans (Gasparro *et al* 1998). More recently, the influence of the UVA in basal cell mutations in human skin has been shown (Agar *et al* 2004). Damage to DNA in melanocytes due to UVA radiation has been observed (Fourtanier *et al* 2006).

The contributions of the UVA irradiances to human exposures have to be considered in environments where there are both unfiltered and filtered solar UV present. Consequently, this paper will report on the erythemal exposures that would be received on a horizontal plane if exposed to the UVA wavelengths only. These will be for a period of a year at a sub-tropical site. The research questions that will be investigated are: What are the erythemal irradiances due to the UVA wavelengths; How these vary with the SZA and cloud conditions encountered over a twelve month period; and What are the resulting times required for an erythemal exposure of one standard erythemal dose.

2. Materials and Methods

2.1 Erythemal Exposures

The erythemal exposures due to the UVA waveband (UVA_{ery}) have been calculated as follows:

$$UVA_{ery} = \sum_{UVA} A(\lambda)S(\lambda)\Delta\lambda \qquad \text{W m}^{-2} \tag{1}$$

where $S(\lambda)$ is the spectral UV irradiance in 0.5 nm increments, $A(\lambda)$ is the erythemal action spectrum (CIE 1987), $\Delta\lambda$ is the wavelength increment of 0.5 nm and the summation is over the UVA wavelengths of 320 to 400 nm to produce the erythemal irradiances due to this waveband. Accordingly, in order to calculate the UVA_{ery}, the spectral irradiance at each 0.5 nm has been multiplied by the erythemal action spectrum at that wavelength, multiplied by 0.5 and summed over the waveband. Similarly, the erythemal UV due to the entire UV waveband, UV_{ery} was obtained by summing over the wavelengths of 290 to 400 nm, with the lower limit of 290 nm used instead of 280 nm as there is no significant irradiance below 290 nm.

The erythemal irradiances have been calculated in units of W m^{-2}. For each five minute interval for which there was a UV spectrum measured, the erythemal irradiance due to the UVA waveband has been calculated, along with the time taken to receive an exposure of 1 standard erythemal dose (SED) to a receiving horizontal plane exposed to that irradiance. An SED is defined as the erythemal exposure equivalent to 100 J m^{-2} (Joint ISO/CIE Standard). This calculation uses the assumption that the irradiance over that period was constant.

2.2 Instrumentation

A UV spectroradiometer (Bentham Instruments, Reading, UK) employed in this research has been reported elsewhere (Parisi and Downs 2004). Briefly, the spectroradiometer based on a monochromator (model DTMc300F) with double holographic gratings with 2400 lines/mm blazed at 250 nm was employed to scan the solar UV spectrum between 280 and 400 nm in 0.5 nm increments. The input optics are provided by a diffuser (model D6) that is connected by a 4 mm diameter, one metre long fibre optic, connected to the input slit of the monochromator. The instrument is located on an unshaded roof of a building at the University of Southern Queensland, Toowoomba, Australia (27.5 ^{o}S, 693 m above sea level) and is housed in an environmentally sealed container. Twelve months of data in 2003 for the times when the equipment was operational were analysed in this paper. The solar zenith angle (SZA) at the site of the spectroradiometer ranged upwards from a minimum of approximately 4^{o} and the data were analysed up to a maximum SZA of 80^{o}.

The system is configured to automatically scan the UV spectrum every 5 minutes of daylight. Each scan takes approximately 2 minutes with approximately another minute for the initialisation of the scan. The irradiance calibration of the system was undertaken at the site against a 150 W quartz tungsten halogen lamp calibrated to the National Physical Laboratory, UK standard and the wavelength calibration was against the UV spectral lines of a mercury lamp. For the period of the data presented in this paper, these calibrations were undertaken on 18 Dec 2002, 15 Jan 2003, 16 Jan 2003, 10 Mar 2003, 17 Mar 2003 and 10 Dec 2003. The uncertainty of the spectral UV data was of the order of ±6% (Parisi and Downs 2004). This does not include the ±3% error associated with the traceability of the irradiance calibration lamp to the UK standard. The percentage variations of the second and subsequent calibrations compared to the first calibration were less than the ±6% error in the spectral data and consequently, no temporal correction has been applied to the data.

During 2003, the irradiance and wavelength calibrations were checked against 150 W QTH lamps and the mercury lamp UV spectral lines. Over the period of the dataset, the instrument was not temperature stabilized and the temperature inside the container housing the instrument that was recorded for each five minute scan and the manufacturer supplied temperature coefficient of -0.4%/^{o}C was applied to temperature correct the data. This temperature coefficient is constant over the UVA and UVB wavelengths.

3. Results

3.1 Erythemal UVA

An example of the UVA spectrum and the spectral erythemal UVA is shown in Figure 1 for a cloud free period in summer (9 January 2003) at 11.55 EST for an SZA of 5^o. The data are in units of mW m^{-2} at each 0.5 nm increment. The steep slope of the solar spectrum that is present in the UVB waveband is not as large in the UVA waveband. The influence of atmospheric ozone on the UVA_{ery} irradiances would be insignificant due to no absorption of ozone in the UVA waveband (Green *et al* 1974). For this example, the ratio of the unweighted UVA to UVB irradiances is 14.8. When the irradiances are erythemally weighted the ratio of the UVA_{ery} to UVB_{ery} irradiances is 0.13.

The erythemal UV due to the UVA waveband is provided in Figure 2 as a function of time of day for a series of the five summer days of 17 to 21 January 2003 (days 17 to 21). Day 17 is relatively cloud free with the other days having different amounts of cloud. Similarly, the bottom half of Figure 2 shows the UVA_{ery} on the five winter days of 16 to 20 July 2003 (days 197 to 201). The days were selected as a sample that had five consecutive days when the UV spectroradiometer was operational and there were cases of both cloudy and cloud free days over the period. The maximum in the UVA_{ery} irradiances on each winters day is of the order of approximately half that of the maximum irradiances in each day in summer. In comparison the erythemal UV due to the entire UV waveband is reduced by a higher factor in the winter compared to the summer. This is due to the higher relative attenuation of the UVB wavelengths compared to the UVA wavelengths for the longer path through the atmosphere at the larger SZA in winter.

This is further illustrated in Figure 3 in the comparison between the UVA_{ery} and the UV_{ery} irradiances for the range of SZA and the cloud and atmospheric conditions encountered during the year at the site. There is a total of 18,479 data points plotted and represent the ratio of the irradiances at each five minutes throughout 2003 when the instrumentation was working. The variations due to the cloud, ozone, aerosols and any other influences are incorporated within the plotted band of values. For the smaller SZA, the UVA_{ery} is of the order of a tenth of the UV_{ery}. In camparison, at the larger SZA of 60^o, the UVA_{ery} is of the order of a third of the UV_{ery} and for an SZA of 80^o, the UVA_{ery} is of the order of 0.5 to 0.6 of the UV_{ery}.

3.2 Times for one SED

The times required over the period of a year for an exposure of one SED due to the UVA_{ery} on a horizontal plane over 2003 are shown in Figure 4 as a function of SZA. The shortest time for an exposure of one SED is 25 minutes. The data are for all sky conditions and the cloud free cases are generally represented by the smaller value at each SZA. The cases for cloudy periods are represented by times longer than those on the cloud free envelope.

The variation throughout the day of the times taken for an exposure of one SED due to the UVA_{ery} and the variation of the times for exposures due to the entire UV waveband are shown in Figure 5 for five days considered in summer (17 to 21 January 2003) and five days in winter (16 to 20 July 2003). For the five days in summer, the minimum time for one SED due to the UVA_{ery} is 32.3 min, compared to 3.9 min for an exposure of one SED due to all the UV waveband. Similarly, for the five days in winter, the minimum time for one SED due to the UVA_{ery} is 61.9 min, compared to 12.6 min for an exposure of one SED due to all the UV waveband.

A histogram of the percentage of the occurrences when the time required for an exposure of 1 SED due to the UVA_{ery} occurs is provided in Figure 6. The time intervals on the x axis are in units of minutes. The maximum occurrence is a time for an SED in the range of 40 to 60 minutes with an occurrence of 20.5%, followed by 15.9% for 60 to 80 minutes. The occurrence for a time of less than 30 minutes for an SED is small at 0.42%, however the occurrence for 30 to 40 minutes is higher at 8.9%.

4. Discussion

This paper has reported on the erythemal exposures due to the UVA waveband, how these vary with the SZA and cloud conditions encountered over a twelve month period and what are the resulting times required for an erythemal exposure of one standard erythemal dose due to these UVA_{ery} exposures. An extensive data set collected at five minute intervals during the day when the spectroradiometer was operational for all weather conditions encountered during the period of a year has been employed. This was at a sub-tropical site for SZA of 4^o to 80^o, however the results should generally be applicable at sites that encounter these SZA.

The exposures due to the UVA wavelengths are applicable for environments where the UVB wavelengths have been removed and the UVA wavelengths are still present. The calculation of the UVA_{ery} irradiances and exposures are based on the assumption that all of the UVA wavelengths are transmitted. This is generally not the case with different amounts of attenuation of the UVA wavelengths occurring, depending on the type of barrier. However, the results provide an upper limit of the erythemal exposures that are encountered for these environments.

The minimum time for an exposure of one SED due to the UVA_{ery} in winter is approximately double that in summer. In comparison, the time for an exposure of one SED due to the UVB wavelengths in winter is longer by a greater factor compared to the time for the same exposure in summer. The comparison between the UVA_{ery} and the UV_{ery} irradiances explains why as it shows that irrespective of the cloud conditions, there is generally a higher relative proportion of UVA_{ery} at the larger SZA compared to the smaller SZA. The same applies at the higher SZA angles encountered earlier in the morning, later in the afternoon and at higher latitudes.

The time period of 40 to 60 minutes was the most frequent length of time for an exposure of 1 SED due to UVA with 60 to 80 minutes the next frequent length of time required for a 1 SED exposure of UVA. There were also periods when an erythemal exposure of one SED would be received in 30 to 40 minutes, with the shortest period being 25 min. The times required for an exposure of one SED due to the UVA_{ery} are reduced compared to those required when exposed to the entire UV waveband. However, for the environments where the UVB wavelengths are not present or have been filtered, there are still significant exposures due to the UVA_{ery} when exposed to the UVA wavelengths for extended periods of time. This highlights the need for further research on the quantification of the UVA exposures to different population groups during normal daily occupational and recreational activities.

ACKNOWLEDGMENTS: *The research reported in this paper is partially supported by a US National Institutes of Health Grant number R01 CA101602-01A2 and the UV spectroradiometer was funded by the Australian Research Council. The authors acknowledge USQ research assistant Nathan Downs and USQ technical staff for assistance in setting up the spectroradiometer.*

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Figure Captions

Figure 1 – The spectral erythemal irradiance in the UVA waveband (heavy line) plotted on the left axis) and the unweighted UVA spectral irradiance plotted on the right axis. The units of the spectral UVA_{ery} and spectral irradiances are mW m^{-2} at each 0.5 nm as the data is recorded in 0.5 nm increments.

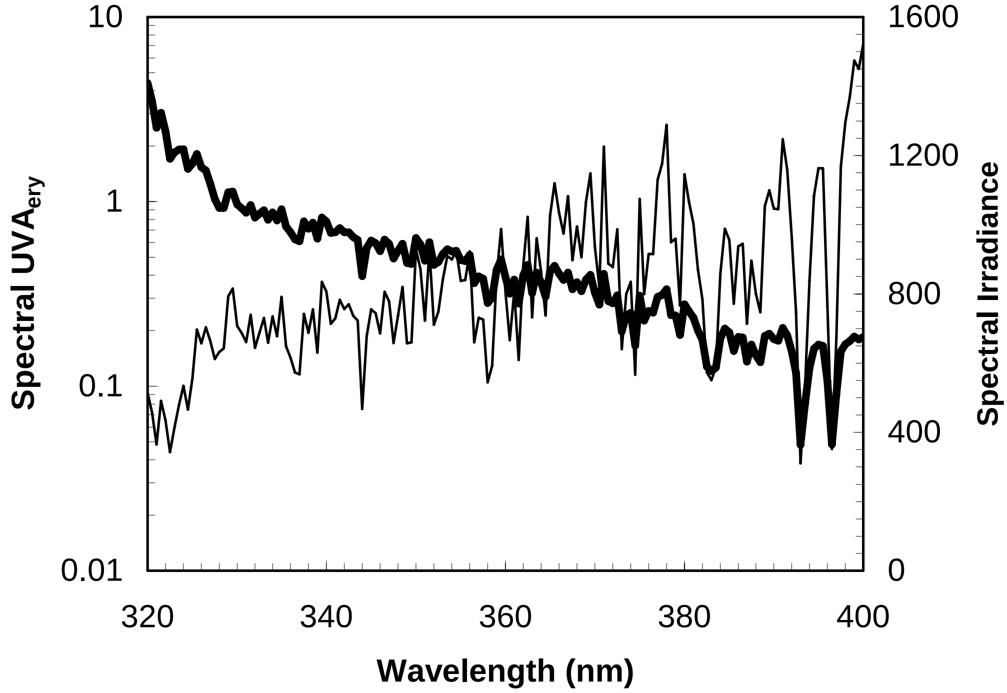
Figure 2 – The erythemal irradiances due to the UVA waveband on the five summer days of 17 to 21 January 2003 (top graph) and on the five winter days of 16 to 20 July 2003 (bottom graph).

Figure 3 – The ratio of the erythemally weighted UVA irradiance to the total UV erythemally weighted irradiance as a function of SZA for all sky conditions during 2003.

Figure 4 – The times required for an exposure of 1 SED due to the erythemal UV in the UVA waveband over a period of a year.

Figure 5 – The time for an exposure of one SED on the five summer days of 17 to 21 January 2003 (top graph) and on the five winter days of 16 to 20 July 2003 (bottom graph). The closed symbols (♦) are the times for the UVA waveband only and the open symbols (○) are the times for exposures to the entire UV waveband.

Figure 6 – Histogram of the percentage of the occurrences when the time required for an exposure of 1 SED due to the UVA_{ery} falls within a certain time range provided in units of minutes.



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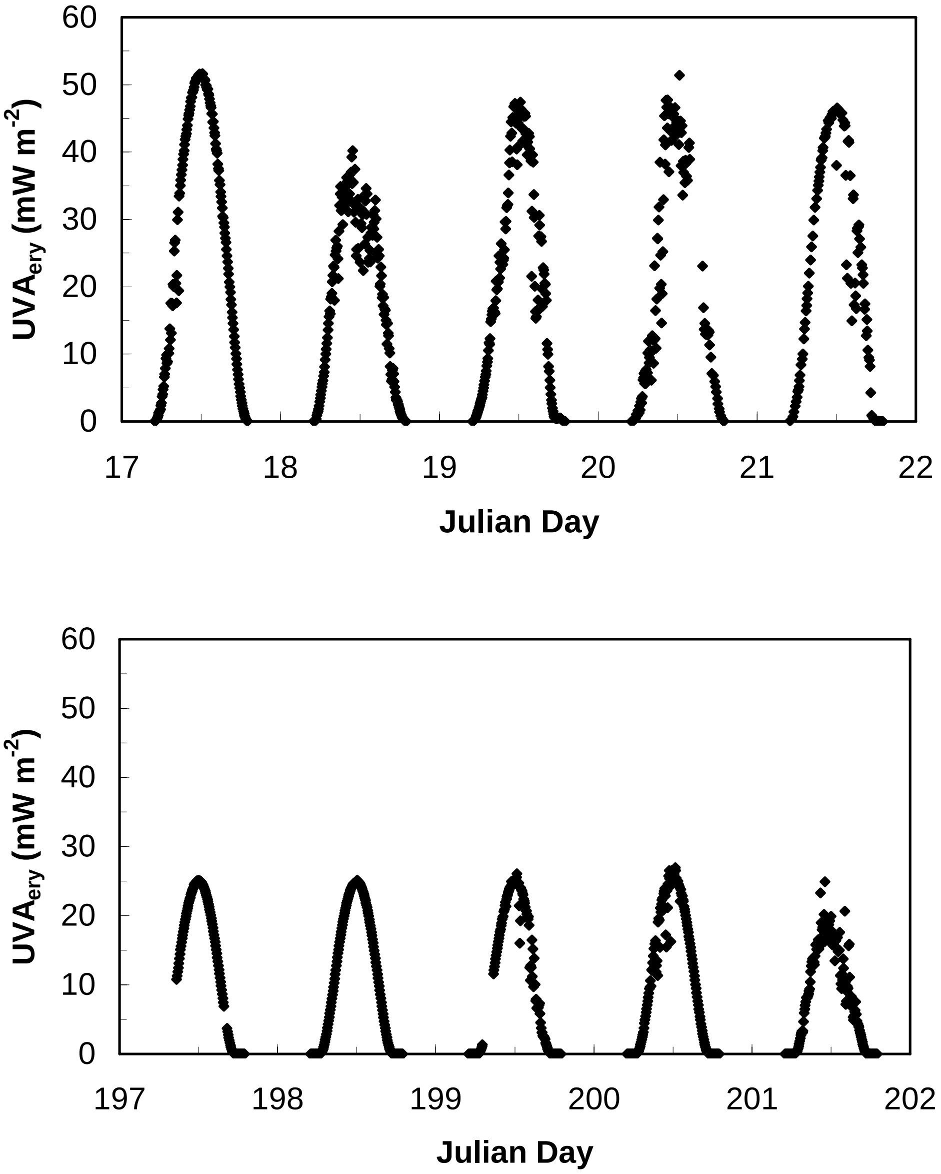

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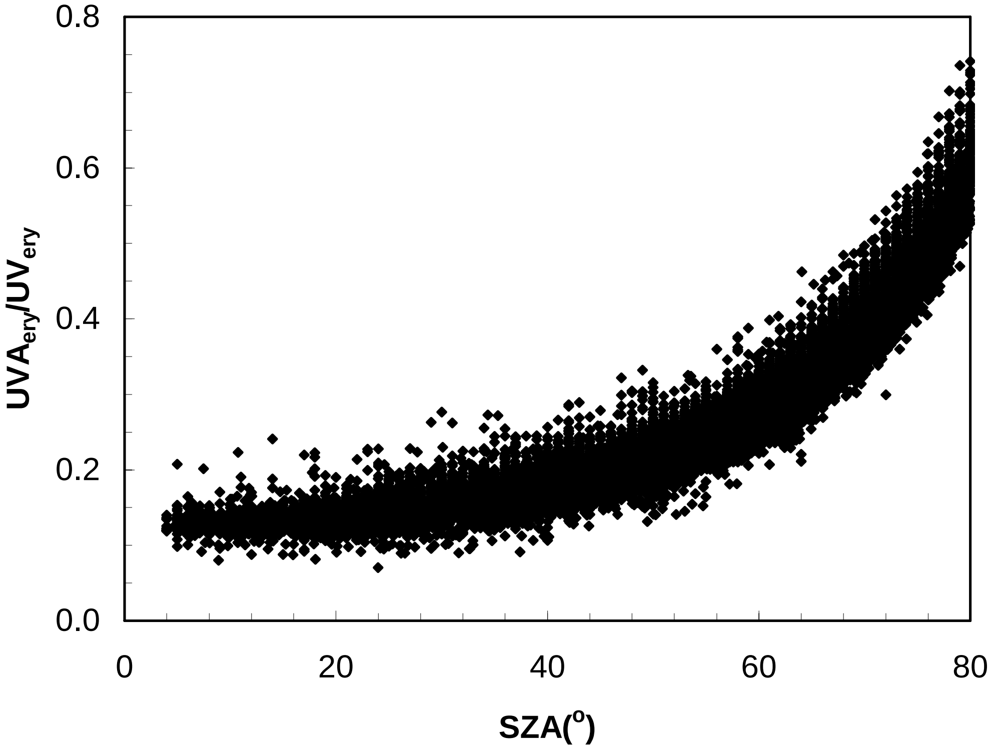


Figure 3 – The ratio of the erythemally weighted UVA irradiance to the total UV erythemally weighted irradiance as a function of SZA for all sky conditions during 2003.

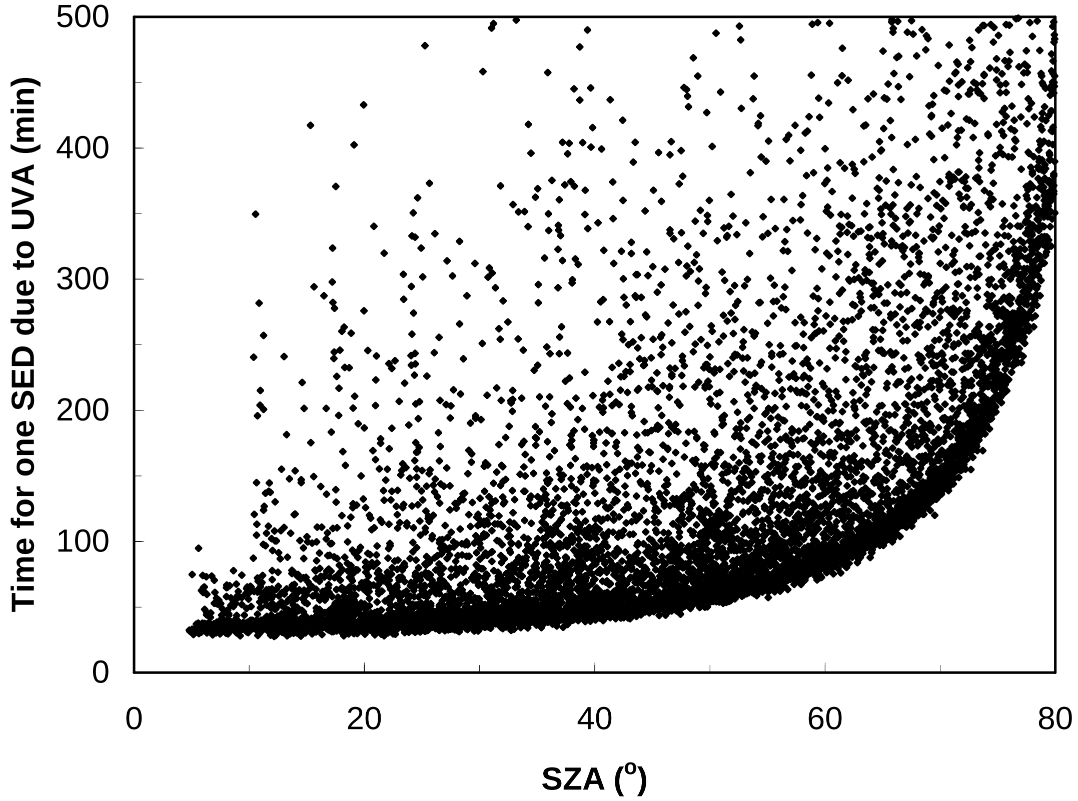
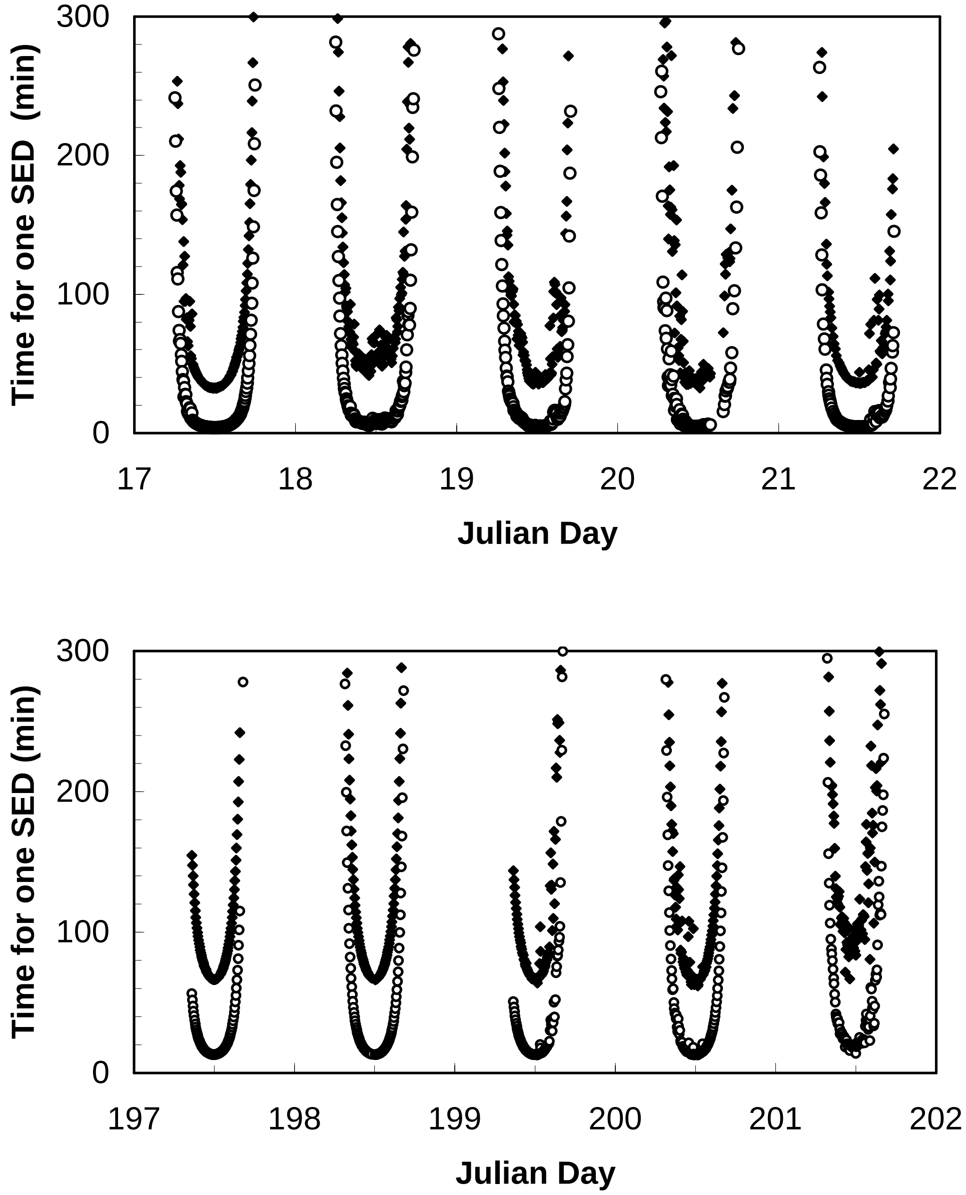


Figure 4 – The times required for an exposure of 1 SED due to the erythemal UV in the UVA waveband over a period of a year.



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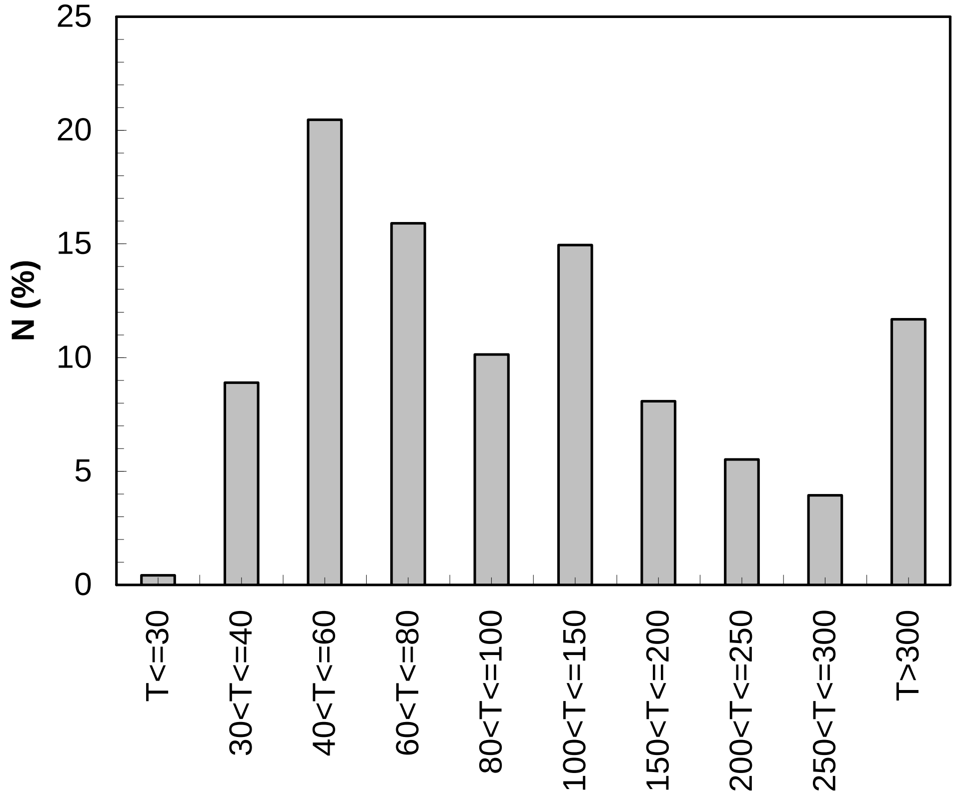

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